VIA MEDICA

Nuclear Medicine Review 2001
Vol. 4, No. 1, pp. 51–55

ISSN 1506–9680

Lecture

New challenges in nuclear medicine instrumentation. The clinician's point of view

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This lecture has been presented at Hungarian SNM Congress in Gyula, 18–20.04.2001.

Introduction

In the last decade, the market of nuclear medicine instrumentation has developed dramatically. On the one hand, highly sophisticated equipment has been introduced, which allows procedures like transmission measurement for image fusion, attenuation correction, scatter correction and automatic body contouring. On the other hand there is a significant demand for imaging facilities at lower costs for routine diagnostics. Since both tendencies are accompanied by an increasing number of mergers, the number of industry partners has been decreasing continuously over the last few years.

The present paper focuses on basic requirements for state-of-the-art gamma cameras and briefly discusses upcoming developments in the field of nuclear medicine instrumentation.

Nuclear medicine instrumentation

General nuclear medicine

The basic instrument of a state-of-the-art nuclear medicine department is the dual-headed whole-body SPECT system. This is the result of technical development in the past decade. Currently, there are two classes of this system available for the nuclear medicine physician:

— The class of high-end gamma cameras offers hardware and software solutions for attenuation correction based on transmission scanning with external radiation sources. This is completed by software solutions for scatter correction. Moreover, solutions for combined SPECT/PET or SPECT/CT devices have been presented by the industry. Although this development significantly stimulated scientific interest in technical problems, these devices inherently have two serious drawbacks: they are not yet sufficiently validated, and they are rather expensive.

— The other class of nuclear medicine devices was designed for the basic requirement of everyday routine patient management. For this purpose, gamma cameras should provide high-quality data acquisition for all organs and all clinical questions, and should be simple to use for the technician. Therefore, both the hardware and the acquisition software should provide high stability in everyday performance. A further important requirement is that data processing should be easily possible with any software system, whatever the user's preferred choice, and they should be offered for a moderate price. Furthermore, the customer service should have short reaction times at acceptable costs. The latter can be ensured by the vendor, when using fairly standardised electronic and mechanical parts, at best for a whole family of gamma cameras.

Nuclear cardiology

Nuclear cardiology has always been an important field of diagnostic nuclear medicine. Therefore, two-headed gamma cameras have quickly become the state-of-the art equipment since they allow the reduction of acquisition time, an increase in patient throughput, and a reduction in the frequency of motion artefacts. For myocardial perfusion SPECT studies, both detectors of the two-headed gamma camera should be allowed to move into a position of 90 or 102 degrees to each other. In a busy nuclear cardiology department, a fixed-angled dual-headed system can be used as an alternative. The striking advantages of such dedicated equipment are the smaller detectors, the more simple mechanics and, in consequence, the lower costs. Gated myocardial SPECT provides additional information about global ventricular function, regional wall motion and myocardial thickening. Recently, the method has become widely accepted and should be implemented for routine patient management, even in low-cost

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equipment. On the other hand, transmission data for absorption measurements are still under clinical evaluation and need further evaluation. The clinical benefit of correction protocols may be hampered by and has to be weighed against the introduction of new artefacts.

Nuclear neurology

In state-of-the-art brain SPECT, triple-headed gamma cameras have become standard in leading edge nuclear medicine departments. However, these gamma cameras were designed originally for SPECT studies of all parts of the human body. Therefore, they are usually equipped with large field of view detector heads, and, thus, inherently have problems in minimising the rotational radius within the contours of the patients´shoulders. Although these problems may be overcome (at least in part) by using dedicated brain SPECT collimators, such as ultra-high-resolution (magnifying) fan beam collimators, image quality can be increased further by dedicated brain SPECT systems built from numerous single small detectors arranged in a ring (e.g. CereSPECT). However, this ultra-specialised system is rather expensive. An interesting compromise has been presented recently by the introduction of the first commercial low-cost 4-headed gamma camera. This device, dedicated for brain SPECT imaging, combines the advantage of an excellent image quality (Figs. 1–6) (due to the small rotational radius of about 13 cm) with a reasonable price. This system offers the opportunity to increase the clinical acceptance of brain SPECT studies significantly despite exquisite morphologic imaging devices with high geometric resolution provided by today's state-of-the-art MRI systems.

Positron emission tomography

Positron emission tomography (PET) is the most sophisticated imaging technology of modern nuclear medicine. For clinical investigations, the full ring PET scanner with 3D acquisition facilities has become the standard equipment. Recent developments are directed towards a further improvement of geometric resolution, increasing the count rate capability by using new crystal materials such as LSO, and a combined PET/CT scanner.

One of the most exciting areas (for research applications) is the introduction of new small animal PET systems, that provide a system resolution of as little as 2 mm, and new designs that allow the resolution of a single microlitre. This development will close the gap between autoradiography in rats and functional imaging in patients. While 100 years ago cellular pathology was introduced by Virchow using histomorphological methods, we have now come down to defining pathology on a biochemical level when using functional defined molecular imaging modalities of nuclear medicine.

Future direction of technological developments

The direction of developments is usually driven by industry and their understanding of the needs of the market. Concerning the need for validation, some of the future challenges of nuclear medicine instrumentation will be listed:

— Image fusion has shown up a lot in scientific life and may have a great impact on the acceptance of nuclear medicine results by the referring clinician. On the other hand, regular and consistent change of image interpretation in routine patient care still has to be proved.

— Transmission in cardiac SPECT with absorption correction may induce artefacts, any clinical benefit still has to be validated.

— Additional scatter correction is needed to obtain results in Becquerels rather than in counts, and there is still possibly a long way to go.

Conclusion

Industry-driven, leading-edge equipment in nuclear medicine pushes the frontier of what is achievable in molecular-defined imaging — becoming a valuable tool for the molecular biologist. On the other hand, for patient care all new equipment features need validation to prove their clinical utility. In the time of cost reduction and ever-increasing need for efficiency new hardware has to be both reliable and cost-effective at the same time. For these goals (new) enterprises should be encouraged.

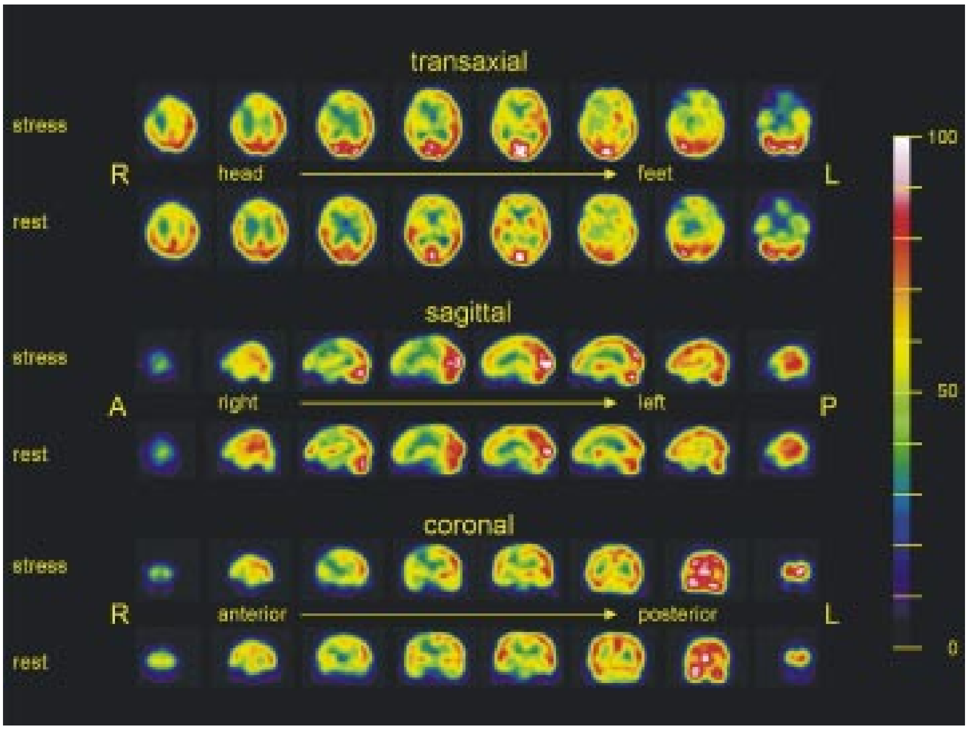

Figure 1. 58-year-old female patient with acute complete occlusion of the right internal cerebral artery, accompanied by hemiparesis on the left side. A 70%-stenosis of the left internal cerebral artery was known in the patient's history. SPECT images were obtained under rest and under pharmacological stress (using a carbonic anhydrase inhibitor) after application of 250 and 750 MBq ^{99m}Tc-ECD, respectively. The stress study revealed a larger perfusion deficit in the right fronto-parietal cortex when compared with the rest study, thereby indicating an impaired perfusion reserve. Additionally, a crossed cerebellar diaschisis was found.

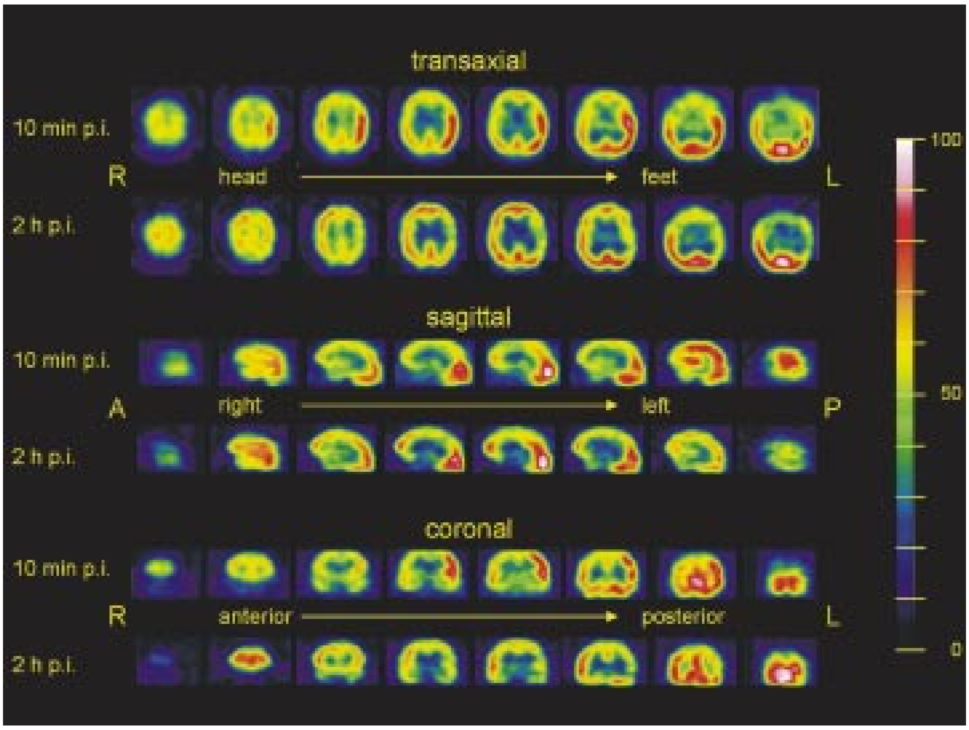

Figure 2. 64-year-old patient with complete infarction of the left medial cerebral artery 10 days earlier. SPECT images were obtained 10 minutes and 2 hours after the injection of 200 MBq ^{123}I-iomazenil. Note the increased (luxury) perfusion in the left parietal cortex in the early images and a corresponding decrease of benzodiazepine receptor density in the late images. Thus, damage of cortical integrity was proved in the left parietal area.

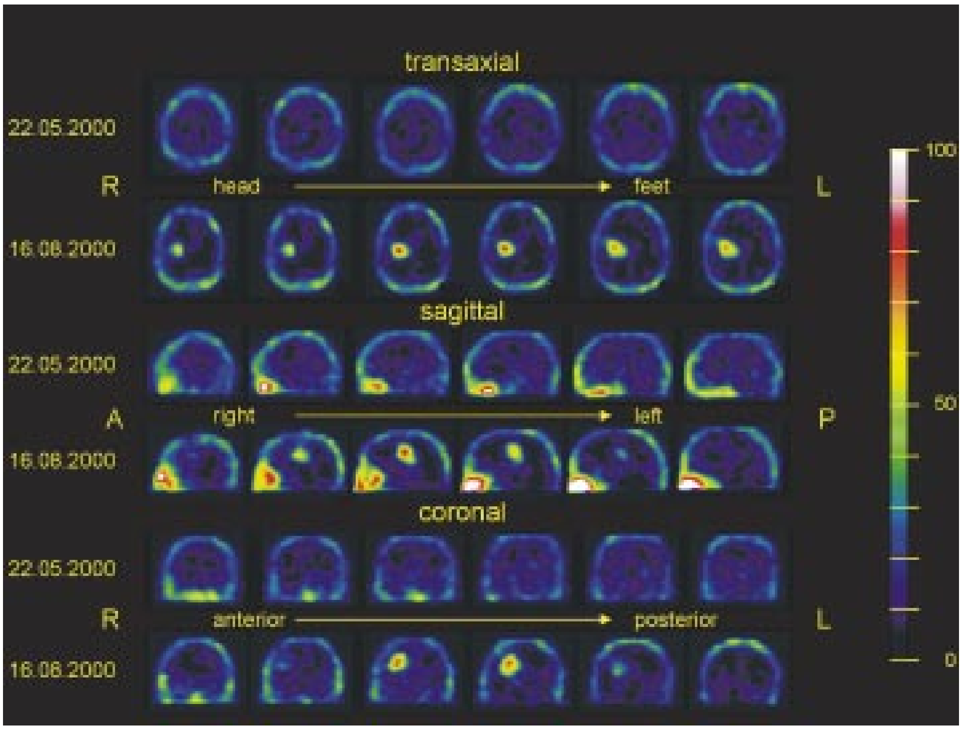

Figure 3. 10-year-old patient with the diagnosis of an anaplastic astrocytoma III° in the right thalamus. The patient was treated initially with chemo- and radiotherapy until 6 months earlier. The first SPECT acquired 2 hours after the application of 100 MBq ^{201}Tl in May 2000 showed a physiological tracer distribution. In contrast, the same study performed three months later revealed a relapse in the right hemisphere.

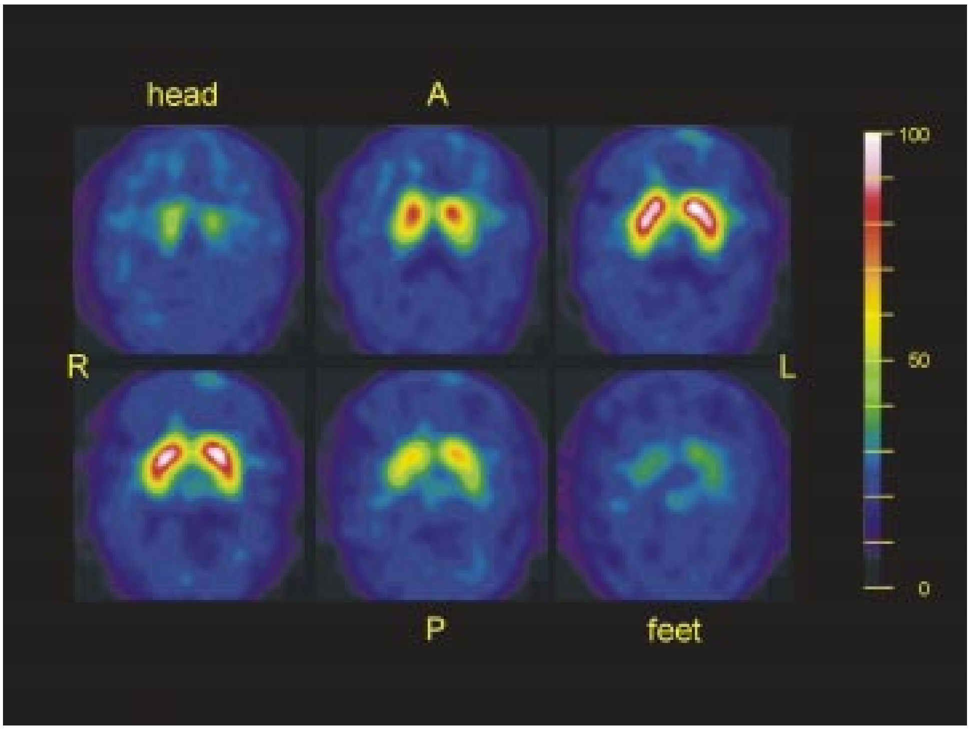

Figure 4. 19-year-old patient with bilateral tremor of the hands. SPECT images were obtained 3 hours after the application of 200 MBq ^{123}I-FP-CIT, a cocaine derivative. This examination was performed in order to differentiate Parkinsonian syndrome from essential tremor. Note the physiological tracer uptake in both striata pointing towards an essential tremor.

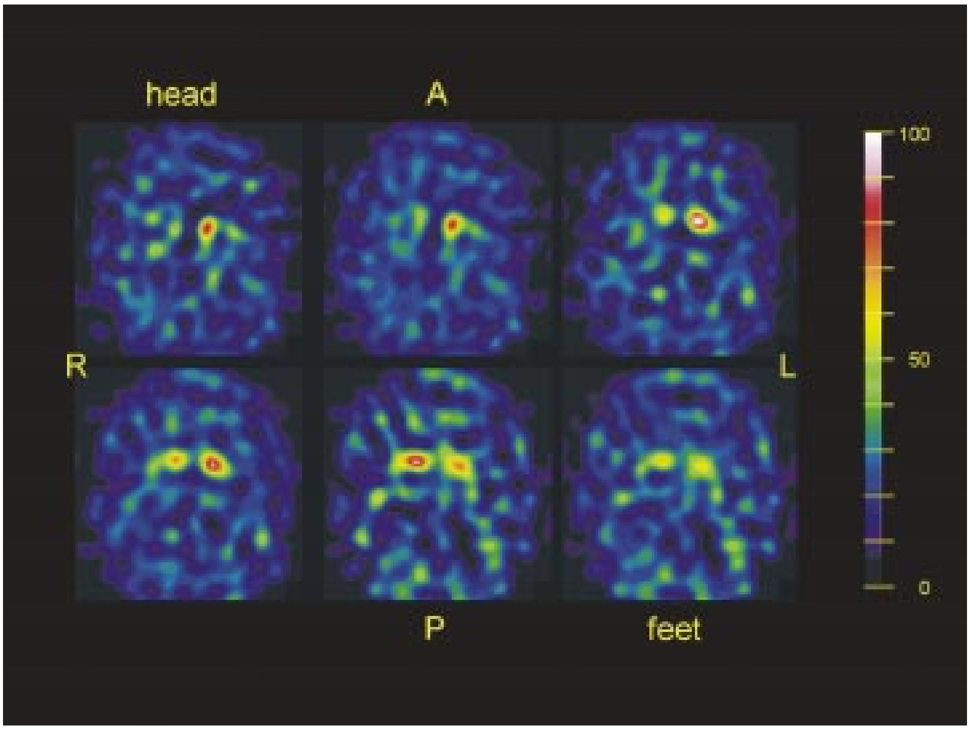

Figure 5. 65-year-old patient with pronounced left-sided Parkinson symptoms for 8 years. The patient's symptoms started with marked tremor, and hypokinesia and dysbalance 3 years earlier. SPECT images were obtained 3 hours after the application of 200 MBq ^{123}I-FP-CIT. Note the bilateral loss of presynaptic dopamine transporter density in the putamen and a marked reduction in the right caudate nucleus, which is consistent with an advanced form of Parkinson's disease.

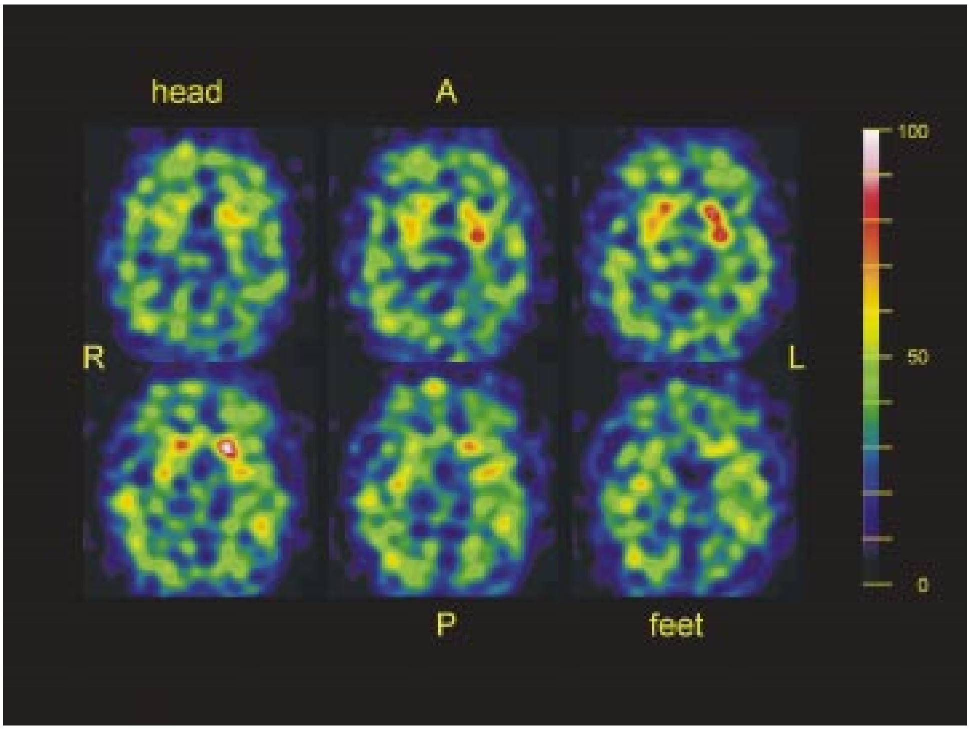

Figure 6. 53-year-old patient with pronounced left-sided akinetic-rigid syndrome. SPECT images were obtained one hour after the application of 200 MBq ^{123}I-IBZM. Note the significantly reduced dopamine D_2 receptor density in the right striatum and in the left putamen, which is consistent with multiple-system-atrophy.